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A Cost Effective Design of Water Purification System for Pharmaceutical Industry

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(Abstract) Pharmaceutical water treatment requires removing contaminants from municipal drinking water to meet The United States Pharmacopeia (USP) standards. There are two basic types of pharmaceutical water; water for topical use or cleaning (sterile purified water, or PW), or water for injection (WFI) which includes sterile water for irrigation and most sterile water for inhalation. For PW, USP guidelines require a conductivity limit of 0.6–4.7 µS/cm, and a bacteria-count limit of 100 cfu/mL. The main difference between PW and WFI is the amount of bacterial contamination allowed, measured by colony count and by endotoxin level. This paper presents a cost effective design of water purification system for pharmaceutical industry, especially in the perspective of Bangladesh. Programmable logic controller (PLC) based design is used for this purpose. The conventional water purification plant costs around US$ 120000 whereas the proposed plant costs only US$ 8000.

Keywords: Water Purification System; USP Standard; Pharmaceutical Industry; Programmable Logic Controller.

1. Introduction

Water purification is the process of removing undesirable chemicals, biological contaminants, suspended solids and gases from contaminated water. The goal is to produce water fit for a specific purpose. Most water is purified for human consumption (drinking water), but water purification may also be designed for a variety of other purposes, including meeting the requirements of medical, pharmacological, chemical and industrial applications. In general the methods used include physical processes such as filtration, sedimentation, and distillation, biological processes such as slow sand filters or biologically active carbon, chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light.

A number of researches have been carried out to achieve the effective design of water purification system. Optimization of coagulant dosing process in water purification system is presented in [1]. Implementation of an Appropriate Household Water Purification System in Tourou, Cameroon is reported in [2]. An EMI mitigation technique in a microcontroller based water purification system is proposed in [3]. A new model and control of water purification system is shown in [4]. Fuzzy logic based control scheme of water purification system is shown in [5].

A power electronics based design of water purification system is proposed in [6] and in [7] neural networks based optimum coagulation dosing rate control applied to water purification system is presented. A highly efficient Capacitive De-Ionization (CDI) water purification system using a buck-boost converter is proposed by [8]. In [9], an optimum control software package for coagulant dosing process in water purification system is developed. Remote Monitoring and controlling system for a water purification plant is reported in [10].

This paper proposes a cost effective design of water purification system for pharmaceutical industry, especially in the perspective of Bangladesh using PLC.

2. Description of the Proposed System

The main units of the proposed water purification system are described in what follows.

(i) Multimedia filtration: Multimedia filters are designed to remove the bulk of suspended contaminants whose size exceeds 10–30 µm.

(ii) Activated carbon (AC): AC beds, also known as activated carbon filters, most commonly are used to remove chlorine and chloramines compound from feed water. This filtration process protects downstream

equipment such as RO membranes and IX resin beads from the damaging oxidizing action of chlorine and chloramines compounds.

(iii) Softening: A softener is a type of IX technology that controls scaling in downstream equipment. A softener controls scaling by removing hard scale–forming cations such as calcium and magnesium and exchanging (i.e., replacing) these ions for non-scale- forming sodium ions. An older term, sodium zeolite softening, frequently is used to describe water softening.

(iv) Ion Exchange (IX) units: IX technology swaps undesirable feed water cations and anions with desirable cations and anions. Cations are positively charged atoms and molecules. Anions are negatively charged atoms and molecules. Cation IX units exchange undesirable feed water cations such as calcium, magnesium, lead, and copper with desirable hydrogen ions. Anion IX units exchange undesirable feed water anions such as chloride, sulfate, phosphate, and nitrate with desirable hydroxide ions. The resulting hydrogen and hydroxide ions then combine to form water.

(v) Cartridge filtration: Cartridge filtration or other pre-filtration technology is used ahead of RO units to protect against fouling from suspended particles in the feed water. RO membrane systems may become fouled if sufficient suspended solids (particulate) removal is not accomplished. Typically, 1–5-μm nominally rated filter cartridges are used.

(vi) Reverse osmosis (RO) water treatment: RO water treatment has become the standard at many pharmaceutical water treatment plants. RO technology can be a cost effective replacement for dual cation and anion IX units. RO systems reduce the need to use costly chemicals, especially those that are caustic, and they curtail the ever-increasing cost of regeneration waste disposal. The payback that results from using an RO system can be achieved in less than two years in some situations. An RO membrane system can remove as much as 98–99% or more of all dissolved contaminants and can remove essentially all suspended (particulate) contaminants. However, RO units require pretreatment to prevent scaling, fouling with living and nonliving particulate materials, and chemical attack, commonly by oxidizing agents.

(vii) UV irradiation: It is used for bacterial control.

(viii) Electrode-ionization (EDI): EDI units in many cases can cost-effectively replace mixed-bed IX units. The resin beads in EDI units do not require chemical regeneration by acid and caustic. EDI units are continuously regenerated electrically.

3. Working Procedure of the Plant

Raw water is collected from bore well water and fed to feed water storage tank through NaClO (Sodium Hypo chlorite) dosing (commonly known as Bleaching powder). A feed water pump feeds water stored in tank. This pump can feed 4000liter of water per hour to the generation unit. Pressure of this water is around 2.5~4 Kgf/cm^2. A pressure cutout controls the pressure of feed water. Fed water is transferred through multimedia filter, carbon bed and water softner. Silicon eliminator is dosed at the entering point of multimedia filter. And at the end of softner $NaHSO_3$ doses the water. Then water is passed through precise filter of 10μ & 5 μ. At this point pre-treatment of the water is completed and pressure of the fed water is almost zero.

Reverse osmosis is the main process for purification of pre-treated water. Pre-treated water is now fed into the generation plant through a multistage vertical pump. This pump reinforces the osmotic pressure for reverse osmosis process. Pressure of this water is around 8~10 Kgf/cm^2. Generation plant is divided into two stages: Stage-I RO & Stage-II RO. In stage-I RO water is passed through 0.0003μ RO membrane (comply chemical sanitization). Once the water comes out of membrane a conductivity sensor measures its conductivity. Acceptable range of this water conductivity is 20~35 μS/cm. Water goes to drain line if it fails to achieve the desired range. And if it is within the range it goes to intermediate tank. A water level sensor controls the water storing and discharging of the intermediate tank. Stored water is fed to Stage-II RO by another multistage vertical pump. The purpose of using this pump is same as the previous one. NaOH (Sodium Hydroxide) is dosed to this water. Pressure of this water is around 8~10 Kgf/cm^2. In stage-II RO water is passed through 0.0003μ RO membrane (comply heat sanitization). Once the water comes out of membrane a conductivity sensor measures its conductivity. Acceptable range of this water conductivity is 5~10 μS/cm. Water goes back to intermediate tank if it fails to achieve the desired range. And if it is within the range it goes to distribution tank through Electro Deionization Unit (EDI)*. Water coming out of EDI is known as purified water. Acceptable range of this water conductivity is 0~1.3 μS/cm. Water goes to intermediate tank if it fails to achieve the desired range. And if it is within the range it goes to distribution tank. A

water level sensor controls the water storing and discharging of the distribution tank. Water stored in distribution is fed to distribution line through a UV lamp by a Distribution pump. It kills the remaining germs in the water. Line Pressure of this water is depends upon the uses at user point. Pressure decreases with the increase of use of water. The unused water is returned to distribution tank. Acceptable range of conductivity for this water is NMT 1.3 µS/cm. Two pneumatic valve controls the incoming and draining of the return water depends on its conductivity.

4. Description of the Control Logic

Raw water is collected from underground and fed to the feed water tank through a controlling pneumatic valve. Controlling of pneumatic valve is depending on the water level of the feed water tank. So for the controlling of water feeding into the feed water tank a water level sensor is used in the feed water tank. If the level of water in the tank is high then pneumatic valve of the feed line remain off. And if the water level goes low pneumatic valve is on and feed water is fed through NaClO dosing. This water is fed to the multi-grade, carbon bed, softner and precise filter (5&10µ) by a feed water pump. During this filtration water is also dosed with silicon eliminator & $NaHSO_3$. A pressure cutout controls pump pressure. If pressure is more than 4Kgf/cm^2, the total pre-treatment plant will shutdown. Water after precise filter is fed into the RO-I membrane by a multistage vertical pump. A pressure cutout controls pump pressure. If the pressure is more than 10 Kgf/cm^2, total pre-treatment plant and multistage vertical pump will shutdown. After passing of RO-I membrane water conductivity is checked. If water conductivity is more than 35µS/cm then water is drained out. Otherwise water is fed into the intermediate storage tank. A water level sensor in the intermediate storage tank also controls water feeding into the intermediate storage tank. If the level is high pre-treatment plant including multistage vertical pump for RO-I membrane will off. And if the level is low supply to RO-II membrane will be off. Water from intermediate storage tank is supplied into the RO-II membrane through NaOH dosing. For this feeding another multistage vertical pump is used. A pressure cutout controls the pressure of this water. If the pressure is more than 10 Kgf/cm^2 multistage vertical pump and NaOH dosing pump will go in shutdown condition. Again water conductivity is checked after RO-II membrane. If the conductivity is more than 10 µS/cm water returns to the intermediate storage tank, otherwise it feed into the EDI unit (Electro deionization unit). To feed into the distribution side the conductivity of EDI, outgoing water must not be more than 1.3 µS/cm. If the range exceeds, the water return to intermediate storage tank. Otherwise water goes to distribution tank. A water level sensor also controls feeding of water to distribution tank. If the water level is high the water feeding will be stopped, and if the level is low supply to the distribution side is stop. A distribution pump distributes water through UV lamp. Unused distributed water returns to distribution tank through the closed loop system. Water is rejected and drained out if the conductivity of return water is more than 1.5 µS/cm.

Table 1 and Table 2 show the input and output of the controller, respectively.

Table 1 Input of the Controller

Serial No.	Items	Type	Future Changes/expansion (proposed)
1	Auto/Manual Change over switch	Digital	Human machine interface (HMI)
2	Generation switch	Digital	
3	Distribution switch	Digital	
4	Neutralization switch	Digital	
5	Pre-Treatment plant pressure high cut-out	Digital	Pressure transducer
6	Stage I RO membrane pressure high cut-out	Digital	Pressure transducer
7	Stage I RO conductivity Transmitter	Analogue	None
8	Intermediate storage Tank water level sensor	Digital	Pressure based water level sensor
9	Stage II RO membrane pressure high cut-out	Digital	Pressure Transducer
10	Stage II RO conductivity Transmitter	Analogue	None
11	pH Transmitter	Analogue	None
12	Distribution Tank water level sensor	Digital	Pressure based water level sensor
13	Back Water Conductivity Transmitter	Analogue	None

Table 2 Output of the Controller

Serial No.	Items	Type	Future Changes/expansion (proposed)
1	Feed Pump	Digital	Feed pump 2
2	Multistage vertical pump 1	Digital	None
3	3-way pneumatic cutup valve (Stage I RO to Buffer Tank)	Digital	None
4	Multistage vertical pump 2	Digital	None
5	3-way pneumatic cutup valve (Buffer Tank to EDI)	Digital	None
6	Distribution pump	Digital	Distribution pump 2 and Inverter for both pumps
7	2 way pneumatic valve (Back water qualified)	Digital	None
8	2 way pneumatic valve (Back water disqualified)	Digital	None
9	2 way pneumatic valve (Stage I RO water drain)	Digital	None
10	2 way pneumatic valve (Stage II RO water drain)	Digital	None

5. Results

The microbiological report of the proposed water purification plant is presented in Table 3.

Table 3 Microbiological Report

E.coli	Salmonella spp.	Pseudomonas aeruginosa
None	None	None
None	None	None
None	None	None
None	None	None
None	None	None
None	None	None
None	None	None
None	None	None
None	None	None
None	None	None

It is observed from the above table that no bacterium is identified after purifying the water using the proposed plant.

The comparison of the proposed plant with the conventional one is shown in Table 4.

Table 4 Comparison

Features	Proposed water plant	Conventional water plant
Looping system	It has looping system	None
Volume flow	As per GMP rule in a water system return water flow at least 1m/s.	None
Sanitization system	Hot water sanitization. So its cost is less.	Chemical sanitization
Continuous water condition checking	Applicable	None
Automated dosing	Applicable	None
Safety	Improved Safety system	None
Filter	Air vent filter included for storage tanks	None
Sanitization Time	After 30 days, improves production facility (3 hrs required)	After 15 days (18 hrs cycle time)
EDI	Applicable	None

It is clearly observed from above table that the proposed plat is more advantageous than the conventional one. More over the cost of the proposed plant is US$ 8000 while the conventional one costs US$ 120000.

6. Conclusion

Water is the most widely used substance, raw material or starting material in the production, processing and formulation of pharmaceutical products. It has unique chemical properties due to its polarity and hydrogen bonds. This means it is able to dissolve, absorb, adsorb or suspend many different compounds. These include contaminants that may represent hazards in themselves or that may be able to react with intended product substances, resulting in hazards to health.

This paper presents a cost effective design of water purification plant for pharmaceutical industry, especially in Bangladesh perspective. The results clearly reveal that the proposed plat is more advantageous and cost effective than the conventional one.

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